GEOLOGY OF THE GREENLAND SANDSTONE, WINSLOW (PENNSYLVANIAN) FORMATION, EASTERN MADISON COUNTY, ARKANSAS

by

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ABSTRACT

The Greenland Sandstone Member of the Winslow (Pennsylvanian) Formation is well exposed in the Boston Mountains of northwestern Arkansas. Paleocurrent measurements in eastern Madison County, Arkansas show that the source area during the time of deposition of the Greenland Sandstone was to the north. Because the Greenland Sandstone is a shallow water marine sand, paleocurrent directions alone are not conclusive. Quartz pebbles present in the Greenland Sandstone are used to help delineate the source direction. On the basis of quartz pebbles and paleocurrents, a definite link between the Eastern Interior Basin and the Boston Mountain area is indicated. Proof of source direction from the north adds strength to the argument that the name Winslow Formation should be retained as originally described instead of the name Atoka as proposed by some.

INTRODUCTION

The Winslow Formation of northwestern Arkansas has not been studied in detail because it is a unit of alternating sands and shales without any apparent lateral continuity. The basal and only named member of the Winslow Formation, the Greenland Sandstone, is the object of this study. The relation of the sandstone to the underlying and overlying units, weathering features, lithology, mineralogy, paleontology, and sedimentary structures are important in this study to help determine the source direction and environment of deposition of the Greenland Sandstone.

The Greenland Sandstone has well-preserved primary sedimentary structures such as planar cross-bedding, asymmetrical ripple marks, overturned cross-bedding, and flute casts that indicate source directions. Mineralogy of the Greenland Sandstone is used to help delineate the probable source direction. Size analysis shows lateral differences in grain size.

Cross-bedding and asymmetrical ripple marks were measured to determine the direction of currents during the time of deposition of the Greenland Sandstone. The results of the measurements show the average cross-bedding current direction to be 186° and the average current direction, as indicated by the asymmetrical ripple marks, to be 170°. Potter and Siever (1956), working with the lower Pennsylvanian sediments of the Eastern Interior Basin, showed that currents were from the northeast and north. The Boston Mountain area lies to the southwest of the Eastern Interior Basin. On the basis of continuity of paleocurrent directions, mineralogy, similarity of environments of deposition, and similarity of types of sediments, it is thought that the Boston Mountain area and the Eastern Interior Basin were continous during the time of the deposition of the Greenland Sandstone. The present Ozark Uplift area, located between the Boston Mountain area and the Eastern Interior Basin, was probably buried under earlier sediments.

Results of paleocurrent measurements strengthen the conclusion that the Winslow Formation should not be correlated with the Atoka Formation, as proposed by some (Croneis, 1930). It should be noted that the foundation of the conclusion lies in the proof of the younger age of the Winslow Formation, determined by goniatites found in it to the west (McCaleb, 1961). Correlation of the Winslow Formation with beds of the Eastern Interior Basin is made on the basis of quartz pebbles, which are entirely lacking in the Atoka Formation of the Ouachita Mountains.

Location and Tectonic Structures

The area of study is located in Madison County, Arkansas, in the Boston Mountain area. The area of study covers 416 square miles, including all or parts of Townships 14, 15, 16, and 17 North, Ranges 23, 24, 25, and 26 West (Fig. 1). Approximately one-half of the bedrock exposures are the Winslow Formation. The area is drained by Kings River and War Eagle Creek, both of which flow to the north. Felkins Creek and Wharton Creek are the major tributaries of Kings River and War Eagle Creek. Streams exhibit a dendritic pattern and a steep gradient, are perennial, and are normally clear. Relief is moderate to rugged, the maximun being about 1100 feet. The northern half of the area has an average relief of about 200 feet and the southern half has as much as 600 feet.

Access is by Arkansas Highways 68, 74, and 23. Other minor highways in the area are Arkansas Highways 16, 21, and 127. Most state highways are paved with low-type asphalt. The remainder of the roads are rough and poorly maintained gravel roads. Most stream crossings are low water bridges and fords, making travel difficult after periods of heavy rain.

The major structural feature in northern Arkansas is the Boston Mountain homocline (Quinn, 1959). The structure is a definite part of the Ozark Dome, the center of which is located in the St. Francois Mountains in southeastern

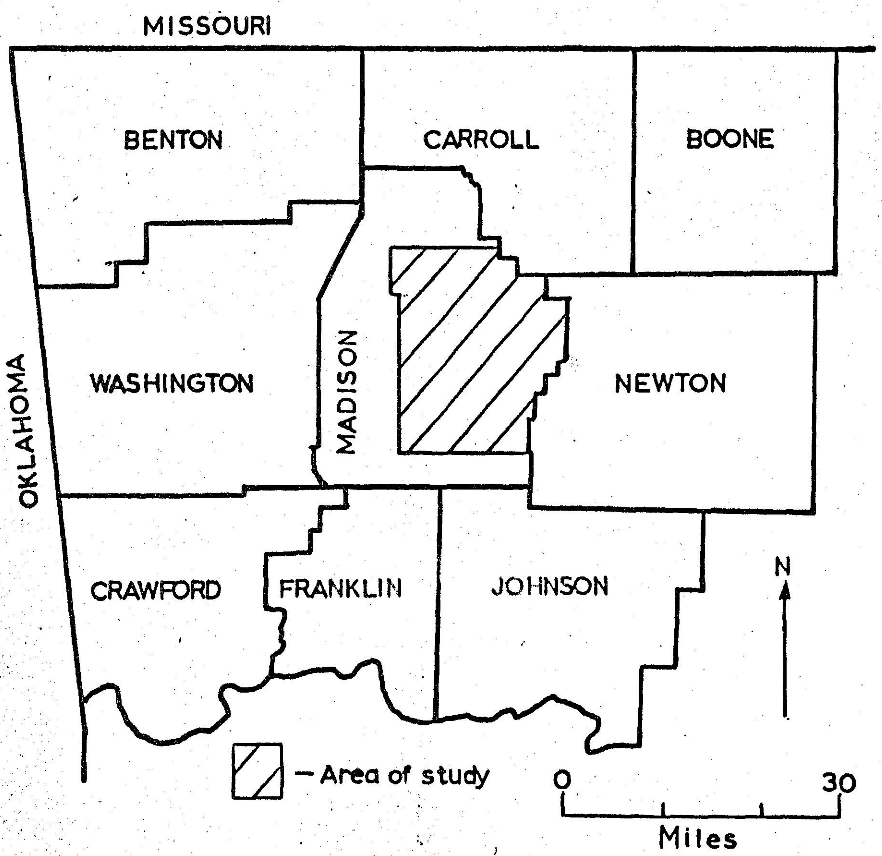

Fig 1. Location of area of study, Madison County, Arkansas.

Missouri. The Winslow Formation sediments are the youngest affected by the homocline. They generally dip south at half a degree but dip up to three degrees in places. The underlying older Morrowan sediments have a more uniform regional dip of around one degree to the south. The variation of the regional dip in the Winslow rocks is because of the nature of sedimentation. Winslow sediments were introduced from a northerly direction and were deposited into the Arkansas Valley Basin as giant "foreset" beds (Quinn, 1959).

No attempt was made to map tectonic structures. No small scale postdepositional structures such as faults or minor folds were observed. The distance between outcrop localities make it difficult to attempt any correlation between outcrops. Vertical control was not needed for the study. In places throughout the area some large-scale structures were seen such as the low dipping limbs of the northeast-southwest trending anticlines. East of the junction of Kings River and Felkins Creek, one can see a dipping limb of an anticline with a difference in elevation of about 50 feet. In general, these anticlines and corresponding synclines are low amplitude and difficult to recognize unless detail mapping of the elevation of key beds is done. Local structures include an east-west trending arch and northeast trending folds (MacEntire, 1964). Small scale structures include a few small gravity faults and collapse structures (Gilley, 1966).

Mapping of Greenland Sandstone

Purdue and Miser (1916) mapped all or parts of Township 16 and 17 North, Ranges 23, 24, 25, and 26 West. This mapping was done in 1916 and is considered accurate enough for purposes of this study. MacEntire (1964) mapped along Highway 23 south of Huntsville. Gilley (1966) mapped in detail T. 16 N., R. 24 W. and Saunders (1967) mapped T. 16 N., R. 25 W. Both these area are included in the 1916 survey. Information as to the location of outcrops of Greenland was obtained from these maps. The rest of the area, including all or parts of Townships 14 and 15 North, Ranges 23, 24, 25, and 26 West, have never been mapped geologically in detail and was mapped during this study to show the outcrop pattern of the Greenland Sandstone (Plate 1).

Mapping of the areas lacking geologic maps was done on aerial photographs made in late October, 1965 by the U.S. Department of Agriculture. Field data from the aerial photographs were transfered to a base map, the Madison County highway map. In many places the Greenland Sandstone is very resistant to weathering and forms a vertical bluff. This type of exposure generally shows up very well on the aerial photographs and proved useful in locating accurately the position of the Greenland.

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WINSLOW FORMATION

The first geologic work on the Paleozoic rocks of northwest Arkansas was done by Owen in 1858. He named the thick sandy, shaly unit that overlies the Bloyd Formation the "Millstone Grit Series", thinking that they were the same age as those in Europe that have the same name. Simonds (1891) described the same unit and retained the name Millstone Grit but called it a formation instead of a series. Adams and Ulrich (1904) changed the name to Winslow Formation, naming it after the town of Winslow, Washington County, Arkansas, where the unit is well exposed.

Croneis (1930) said that the name Winslow should be dropped in favor of the earlier established name Atoka. The Atoka Formation was named by Taff and Adams (1900) for typical exposures around the town of Atoka in southeastern Oklahoma. Croneis believed that if both units rest on rocks that contain a Morrowan fauna and both units are overlain by the Hartshorne Formation, they should have the same name; and Atoka was first used to name units that fit this description, therefore it should be the name retained. Croneis also believed that the Winslow of the Boston Mountain region continues into the Atoka of the Arkansas Valley.

Suggesting that the name Winslow was a valid name, Miller and Downs (1948) said:

> "..., in the opinion of some geologists, it may have been a mistake to abandon this term [Winslow], because the beds at Winslow, though named later than the Atoka Formation, are not involved in a complicated structure and can be fitted with more certainity into the unparalled section from the Ozark uplift to central Kansas by way of Arkansas."

Investigations by McCaleb (1961) furnished good evidence on the basis of paleontology and mineralogy that the name Winslow is valid and should be reestablished. He said:

> "1. Paleontological data collected from the Winslow Formation indicates it is younger than the underlying Bloyd Formation and older than the Atoka Formation.
>
> 2. The Winslow and Atoka Formation can be differentiated on the basis of lithology, the Winslow is a pure quartz sandstone, whereas the Atoka is subgreywacke.
>
> 3. The Winslow and Atoka sediments were derived from different sources. The Atoka sediments were probably from the south, whereas the Winslow sediments were derived from the north or northeast."

As a result of studying an assembledge of goniatite cephalopods, Quinn (1962) reached a similar conclusion and stated:

> "If the synonymy is recognized, it becomes necessary to coin the term 'Boston Mountain Atoka' to distinguish the section. It seems preferable to retain the old name rather than to employ a new one, which is precisly the outcome of recogniyion of the synonmy."

Heavy mineral studies have been made on the sands of the southern Boston Mountains and the Forche Mountains of of the Ouachitas by Weigel (1958) and Mosely (1962). Weigel found a metamorphic suite of minerals in the southern mountains and no equivalent minerals from the Boston Mountain sands. This would suggest a source for the Boston Mountain sands from some direction other than south. Mosely's study of heavy minerals revealed a predominance of plagioclase feldspars in the basal unit [Greenland] and a greater amount of potash feldspars in the upper unit.

In support of the idea that the Winslow source area was to the north, Quinn (1959), who now uses the name Winslow, said:

> "During Atoka time in the western embayment, sediments introduced from a northerly direction were deposited and built out into the Arkansas Valley Basin as giant 'foreset' beds. This is shown by the fact that the 'average' dip of Atoka strata along the Boston Mountain front is considerably greater than the dip of the underlying Morrowan which is approximately one-half degree. Also the Atokan sands have developed extensive penecontemporaneous slump structures on a large scale which does not appear possible on surfaces of less than one degree dip."

The present study confirms that the source of the Greenland Sandstone at the base of the Winslow was indeed to the north. The average current direction during this time was 186° as indicated by planar type cross-bedding. Measurements of asymmetrical ripple marks indicates an average current direction of 170°. In view of these findings, the name Winlow will be used when referring to the units above the Bloyd Formation. Briggs (1963), studying paleocurrents in the

Arkoma Basin in southeastern Oklahoma, demonstrated that the average current direction of paleocurrents of what he calls Atoka Formation is 182°. This direction is consistent to the Choctaw fault, where there is a sharp change in direction to the east. Perhaps this is an indication that the southern extent of the Winslow Formation is in this region.

UNITS UNDERLYING THE GREENLAND SANDSTONE

The Greenland Sandstone rests with unconformity on the earliest Morrowan formations, the Hale and the Bloyd Formations (Fig. 2). The Hale Formation consists of two members, the Cane Hill at the Base, and the Prairie Grove at the top. The Bloyd Formation consists of five members, the Brentwood Limestone Member at the base, the Woolsey Member, the Dye Shale Member, the Kessler Limestone Member, and the Trace Creek Shale Member. The Bloyd also contains the Gaither Mountain "horizon", a limestone pebble conglomerate that has not yet been fully described. Because fossils are often lacking, lithology of the underlying units must be used to determine the unit the Greenland rests on. Lithologic descriptions of the Hale and Bloyd Formations follow.

Hale Formation

The Hale Formation, of earliest Morrowan age, is divisible into two mappable units, the lower named the Cane Hill Member, and the upper named the Prairie Grove Member. The following information was obtained by Henbest (1953) except as noted.

Cane Hill Member

The Cane Hill Member is a silty to fine-grained sandstone. Thickness ranges from zero to 65 feet. Locally the unit is calcareous or consists of shaly siltstone alternating with thin, hard beds of fine-grained sandstone. Ripple

SYSTEM	SERIES	FORMATION	MEMBER
PENNSYLVANIAN	MORROWAN	WINSLOW	GREENLAND
		Unconformity	
		BLOYD	TRACE CREEK
			KESSLER
			DYE SHALE
			WOOLSEY
			GAITHER MT ?
			BRENTWOOD
		Unconformity	
		HALE	PRAIRIE GROVE
			CANE HILL
		Unconformity	
MISS.	CHESTER	PITKIN	
		FAYETTEVILLE	

Fig. 2. Generalized Late Paleozoic stratigraphic column, northwestern Arkansas.

marks and cross-bedding are common. Fresh surface color is dark grey to black, but the unit weathers to a medium gray to brown. The base of the unit contains lenticular bodies of limestone conglomerate composed of rounded cobbles or boulders from the underlying Pitkin Limestone of Mississippian age. This conglomerate represents locally derived sediments. Saunders (1967) said the thickness of the Cane Hill ranges from 80 to 195 feet thick in the Wharton Creek area. The basal conglomerate contains broken and incomplete ironstone concretions from the Fayetteville Formation which underlies the Pitkin Formation. Saunders (1967) reported one rounded quartz pebble one inch in diameter collected from the basal conglomerate. This may be an indication that the Eastern Interior Basin had become a source area for the sediments of northwest Arkansas as will be described later.

Prairie Grove Member

The Prairie Grove Member of the Hale Formation is largley a calcareous, fine- to medium-grained sandstone. Thickness of the unit ranges from 60 to 200 feet. Cross-bedding and burrows which weather to a honey-comb type structure are the most common characteristics of the Prairie Grove. The upper part of the member may contain fossiliferous, crinoidal limestone. A thin zone of cherty nodules has been reported from the upper part on Kessler and Bloyd Mountains (Henbest, 1953). This chert may have been derived from the

Ozark Dome to the north where abundant cherts crop out. The color of the unit ranges from tan to reddish brown on the sandstone surfaces and is light gray on the relatively pure limestone surfaces. Saunders (1967) reported liesegang structures prominent on many of the sandstone surfaces. Many of the sandstone lenses in the Prairie Grove are up to 30 feet thick and forms small, discontinous bluffs.

Bloyd Formation

The Bloyd Formation consists of the Brentwood Limestone Member, the Gaither Mountain "horizon", the Woolsey Member, the Dye Shale Member, the Kessler Limestone Member, and the Trace Creek Shale Member. The Bloyd Formation was assigned to the Morrow Group by Purdue (1907).

Brentwood Limestone Member

The lithology of the Brentwood Limestone is varied but it consists mainly of alternating layers of more or less cross-bedded, lenticular, or uneven-bedded limestone and layers of shale. Some limestone beds are sandy and often are cut into an underlying shale. The base of the Brentwood is separated from the underlying Prairie Grove Member by a dark, slightly fissile shale 18 inches thick. The top of the Brentwood is a disconformity with the terrestial sediments of the Woolsey resting on the Brentwood.

Gaither Mountain "horizon"

The Greenland Sandstone, in the area of study, is generally found on what appears to be the not yet formally recognized Gaither Mountain "horizon". At present William McMoran of the University of Arkansas is in the process of describing this horizon in the vicinity of Harrison, Arkansas. McMoran visited several localities in this study area and commented on the remarkable lithological similarity with the Gaither Mountain "horizon" near Harrison, Arkansas. A thorough search failed to turn up the characteristic goniatie fossil of the unit, the Gaitherites solidum (Quinn, personal communication). Yet on the basis of lithology, its position above the Brentwood Limestone, and the presence of the goniatites Branneroceras and Syngastrioceras and the gastropod Pharkidonotus found there, leads the author to believe that this is the equivalent of the Gaither Mountain "horizon" in this area.

The limestone conglomerate below the base of the Greenland is a dense, medium gray, fossiliferous, conglomeratic limestone. It contains well-rounded limestone fragments, claystone, siltstone, and sandstone pebbles, many up to 4 inches in diameter. Most of the fossils are crinoid stem segments, colonial and solitary corals, blastoids, brachiopods, and gastropods which show evidence of rounding, indicating that they were subjected to abrasion only long enough to round them and not to destroy them. The pebbles are in a fossiliferous, silty, sandy, limestone-cemented matrix. Thickness ranges from 2 to 4 feet.

Fossils of this unit, according to Saunders (1967), include the goniatites Gaitherites solidum, Branneroceras branneri, Syngastrioceras morrowense, Bisatoceras secundum, Proshumardites sp., Pronorites sp., and the gastropod Pharkidonotus sp.

Absent members

The remainder of the members of the Bloyd Formation are not known to crop out in the area of study. They were probably eroded after their deposition in this area. As they may be present in nearby areas, a brief description is included. The Woolsey member contains terrestrial strata up to 45 feet thick, composed of limestone conglomerates, siltstones, and sandstones. The Dye Shale Member varies from a conglomeratic, calcareous marine sandstone to a dark colored siltstone and shale. Thickness ranges from 60 to 110 feet. In this interval is the "caprock of the Baldwin Coal" (Quinn, personal communication). The "caprock" is the first bed in which quartz pebbles are found in any abundance.

The Kessler Limestone above the Dye Shale is an oolitic, light colored limestone with many "algaloid" nodules in the upper part, giving it the appearance of a coarse conglomerate. The Trace Creek Shale Member, named by Henbest (1962), is basically a dark-gray to black marine shale, with sandy calcareous zones and a few thin limestone beds. Thickness is as much as 125 feet but averages 60-70 feet. Henbest (1962) said that the Trace Creek is gradational with the underlying Kessler Limestone and may interfinger with the overlying Winslow Formation.

GEOLOGY OF THE GREENLAND SANDSTONE

The Greenland Sandstone is the most resistant unit in the area and forms a prominent cap rock on the outliers of the Boston Mountain. The outliers of Greenland stand on the platform of the Springfield plateau (Henbest, 1953) which is underlain by the resistant chert of the Boone (Mississippian) Formation. The Greenland Sandstone Member of the Winslow Fomation (Fig. 2) was first named by Henbest (1953). It was named for characteristic exposures near the town of Greenland, Washington County, Arkansas, and is well exposed in Madison, Washington, and Newton counties, Arkansas. Future investigations will probably reveal that the Greenland has a greater areal extent, especially to the east. The Greenland forms a bench that can be traced for considerable distances. The persistance of the Greenland makes it useful as a stratigraphic marker. It is easily recognized on aerial photographs. Mapping of the base of the Winslow can be easily done by observing the outcrops of the Greenland. Where the Greenland is not well exposed, its position is usually well marked by a distinct break in slope.

The Greenland was described by Henbest (1953) as a "silty ripple-marked, flaggy sandstone with shaly partings." He described local marine quartz-gravel conglomerates lying at the base of the unit or interfingering with the sands at higher levels. In the area of study, the Greenland is a light to medium yellow-tan, very fine- to medium-grained, cross-bedded, ripple-marked, quartzose sandstone with a quartz cement and some interstitial limonite. The Greenland, in most outcrops, contains quartz-pebble conglomerates, with pebbles up to 36 mm long. The beds are almost devoid of invertebrate fossils but abound with fossil plant fragments, the majority of them being unrecognizable.

The most abundant cement in the Greenland is quartz. Calcareous portions of the Greenland were not found in the area of study. In some places, the cementation by quartz is so complete that the rock fractures across the grains instead of around the grains. In most localities, the quartz cementation is only enough to make the Greenland very resistant to weathering and erosion.

Almost every outcrop of Greenland shows cross-bedding of the planar type (McKee and Weir, 1953). Ripple marks and some flute casts are present. Quartz pebbles occur from the base of the unit to the top. In some outcrops quartz pebbles are abundant and in others, completely absent. It is thought that the presence of quartz pebbles may indicate areas of stronger currents, possibly areas of channels.

Weathering of the Greenland Sandstone

The Greenland Sandstone on fresh surfaces is light to medium yellow-tan in color. The Greenland has a small amount of interstitial limonite which is concentrated on weathered surfaces to produce a thin zone of dark-colored, case-hardened sandstone. In some places where the sandstone is not directly exposed to the elements, such as under an overhang of the bluff, the iron stain takes on the appearance of specular hematite. In most places the surface color of the Greenland is a speckled reddish-brown gray to medium gray-black. Lichen often gives the exposure a mottled apperarace.

Differential weathering of the Greenland reveals the bedding and cross-bedding and other sedimentary structures of the Greenland. The differences in rates of weathering are generally very small, with only about 0.5 inch average of relief developed. Cementation in the coarser portions of the sandstone makes these areas stand out. In some places, the Greenland takes on a massive appearance and "pock mark" weathering takes place (Fig. 3). "Pock mark" weathering is differential weathering of the Greenland which produces a deep pocket with a thin wall of sandstone separating one pocket of weathering from others. This must be due to weathering beginning at a point and spreading out from there.

Fig. 3. Exposure of Greenland Sandstone showing "pock mark" weathering. Outcrop 138.

Cliff Overhangs

Slightly faster weathering of the underlying units often produce an overhang of the Greenland. When an overhang becomes too great to be self supporting, the overhang breaks off, falling down the hill side. Many of the fallen boulders are as large as an average house. Cliff overhangs are important because they expose the third dimension of the outcrop and expose the underlying units that would normally be covered with weathered material. Exposure of the third deminsion is important in that it allows the true strike and dip of the cross-bedding fore-set beds to be measured.

As a result of differential weathering, undercuts have developed in the underlying layers, causing overhangs of the Greenland (Fig. 4). These undercuts are in some places 300 feet above the present day stream level. Quinn (personal communication) said that the valleys now have their maximum alluvial fill. Therefore the undercuts cannot be due to stream action. Quinn (1958) suggested that in light of the absence of freshly fallen blocks of Greenland and the presence of large quantities of dust beneath the overhangs, that process of formation of the overhangs is cliff sapping. This process requires the underlying material to weather into dust or fine grain material that can be removed by wind action. Removal of the fine material would have been accomplished during a time when the

Fig 4. Overhang of the Greenland Sandstone resting on the Brentwood-Gaither Mountain "horizon". Girl is standing on the Brentwood Limestone near the entrance to a solution cave. Outcrop 138.

climate was dryer and there was no heavy vegetation to block the wind. Quinn (ibid) said that for the most part the overhangs are Altithermal in age, that is, they have formed since the last glaciation.

If conditions were such that the underlying units below the Greenland could weather into a dust that could be easily removed by wind action, would one not expect to find a tendency for the overhangs to generally parallel the wind direction at the time of formation? But the overhangs found today are orientated in almost every direction but always parellel with the stream valley below, which indicates that the overhangs retreat parallel to the stream valley.

While the author admits that Quinn's method of cliff sapping is feasible, observation of many overhangs suggests other possibilities. There are several factors to take into consideration; (1) the Greenland Sandstone has a high porosity in spite of the fact that it contains a large percentage of quartz cement, (2) there is a high annual rainfall in the area of around 40 inches per year, (3) active erosion of the Greenland is taking place today as evidenced by the numberous rocks that fall each year, and (4) by the fact that some places once inhabited by Indians are now covered with fallen rock.

These factors, coupled together with the lithology of the underlying units suggest that the overhangs are the result of groundwater action. Groundwater percolating down through the Greenland, reaches the underlying limestone conglomerate and disolves the calcite, leaving the clay and insoluble material behind. An insoluble residue study of one sample has shown that the underlying limestone conglomerate is approximately 85 percent clay and insoluble material. This would account for the large amount of yellow clay material found under the bluffs. In some places the yellow clay is conglomeratic, probably due to incomplete solution of the limestone. This leaching process would only work where the Greenland rests on a limestone or limestone conglomerate.

Where the Greenland rests on a shale bed or siltstone or sandstone, the groundwater would still percolate downward through the Greenland, reaching the underlying unit. Then during winter freezing and thawing the resulting spewing or frost heave can break up the underlying material. When thawed, the loose spewed material will fall to the base of the outcrop. With assistance from animals and man using the overhangs for shelter, there seems no doubt that the overhangs could have been produced by this method. Time involved in their formation would be on the order of a few thousands of years. Other evidence for the action of groundwater dissolving out the underlying units is the numerous small caves found at the contact of the Greenland and the underlying limestone. There are springs that issue from below the base of the Greenland. Also numerous solution channels are found in the underlying limestone.

Basal Contact

The basal contact of the Greenland Sandstone with the underlying units is unconformable. The Winslow rests on progressively older beds to the north (Quinn, 1959) as a result of uplift of the area after deposition of the Bloyd, followed by tilting of the area to the south and subsequent erosion. The contact at the base of the Greenland Sandstone is very regular and sharp, with only gentle relief of 3 to 6 inches. There is no evidence of channeling at the base of the Greenland except at one place where it rests on a shaly portion of the Bloyd. There, in incomplete exposure, is a small sand channel cut approximately 2 feet down into the shale. The full width of the channel could not be determined. It must be kept in mind that the direction of the currents carrying the Greenland sands was basically north-south, and the present day drainage is also basically north-south. This limits most outcrops of the Greenland to sections viewed parallel to any channels that may be present. Therefore, channels of greater magnitide may be present but are obscured.

Basal Conglomerate

The base of the Greenland is generally very sharp and abrupt. In many outcrops a basal conglomerate is lacking. In places the basal conglomerate is confined to a layer about 2 to 4 inches thick consisting mainly of large (up to 4 inches) clay pebbles and quartz pebbles, all mixed in a matrix of fine to medium sand cemented with quartz and some interstitial limonite (Fig. 5). As the Greenland rests with unconformity upon units that are mainly shales and limestones, and because in most places the underlying horizon resembles the Gaither Mountain "horizon", the source of the clay pebbles could possibly be the underlying limestones.

Insoluble residue analysis of the underlying unit has shown that the unit contains up to 85 percent clay and fine silt with only a small amount of calcite cement. Therefore, if the underlying limestones were eroded and rounded by the processes of transportation, deposited, leached by groundwater, and then partially cemented with secondary limonite, the result would be the clay pebbles found at the base of the Greenland.

Due to the fact that the Greenland represents a fairly high energy environment as shown by the large quartz pebbles, the clay pebbles must have been resistant while they were being transported. It is unlikely that any mud or silt being carried in a stream and exposed to drying could be consolidated or cemented enough to survive the high energy that

Fig. 5. Basal conglomerate of the Greenland Sandstone showing clay pebbles. Clay pebbles have been weathered out, leaving cavities. Outcrop 139.

would be encountered on the way to the site of deposition. However, clay pebbles are not confined to the basal conglomerate. A few are found near the top of the Greenland. Closer examination may reveal that there are some differences in the pebbles, the lower ones being derived from the underlying limestone conglomerate and the upper clay ones from some other source.

Paleocurrent Indicators in the Greenland Sandstone

Paleocurrent directions of the Greenland Sandstone were studied to (1) determine the direction of sediment transport and possible source areas for the Greenland Sandstone, (2) determine changes in paleocurrent direction over the area of study, and (3) determine the relationships of the paleocurrent directions in the Boston Mountains and those of the Eastern Interior Basin.

Cross-bedding (Fig. 6) of the planar type (McKee and Weir, 1953) is the most common and prominent paleocurrent indicator present in the Greenland Sandstone. Slight differential weathering of the sandstone results in a small relief of the weathered surface, exposing the cross-bedding. Ripple marks are common and flute casts are found only where the Greenland tends to be silty. Only cross-bedding and ripple marks were measured, the flute casts not being considered due to their scarcity and poor preservation. Festoon type cross-bedding was observed in only one outcrop. Ripple marks of the asymmetrical and oscillatory type are

Fig. 6. Typical outcrop of Greenland Sandstone showing cross-bedded and horizontally stratified layers. Vertical scale is about 15 feet. Outcrop 137.

found in every horizon of the unit are are best exposed on top of outcrops. Ripple marks were observed on top of the cross-stratum, indicating that ripple marks were developed on the upper surface before deposition of the next set of cross-strata.

Average thickness of the cross-strata is 18 to 24 inches, but may be as much as 4 feet. According to terminology proposed by McKee and Weir (1953), the Greenland would be thinly to thickly cross-bedded. Quartz pebbles are generally found on the contacts between the cross-bedded strata and between horizontally bedded layers. In no case were plant fossils found resting on the foreset bedding, only on the horizontal bedding separating the cross-bedded strata.

Not every stratum of the Greenland shows cross-bedding (Fig. 7); some layers are massive. Apparently unstratified layers occur in succession or scattered throughout many other layers that do show cross-bedding. Possibly the weathering has failed to expose cross-bedding, or perhaps non-stratification indicates a time when the currents were not as strong and did not form cross-bedding. Close examination shows that the individual cross-strata exhibit graded bedding. The coarser sand particles are at the base of the cross-strata and grade upward toward finer sand-size particles. Figure 8 illustrates this feature.

Ripple marks are best exposed beneath overhangs of the Greenland or on top of outcrops. In some locations, the tops of the cross-strata show ripple marks, but do not always

Fig. 7. Outcrop of Greenland showing thickly bedded planar cross-bedding. Upper half of outcrop does not exhibit cross-bedding. Outcrop 130.

Fig. 8. Negative photograph of thin section No. 176 showing graded bedding of cross-bedding. Note quartz pebbles. X2

indicate the same direction of current movement as does the cross-bedding. The maximum difference in current direction is generally not more than 30 degrees. This is thought to indicate that the direction of currents shifted frequently during deposition of the Greenland.

Azimuthal readings of the cross-bedding and ripple marks were made with a Brunton compass graduated from zero to 360°. This type of graduation was used to reduce the error in transcribing measurements and to facilitate the computation of mean current direction. Strike and dip of the foreset beds of the cross-bedding was measured. Direction of current travel was assumed to be at right angles to the strike of the cross-bedding in the direction of dip of the foreset beds. There are no indications that the ripple marks were formed by antidune ripples migrating upstream. Direction of current travel was measured on asymmetrical ripple marks whose strike and apparent direction of current flow, whether to the north or to the south, was recorded. A maximum of six readings of cross-bedding was taken at each outcrop. Three readings were taken of ripple marks. These numbers were considered sufficient as no corrections are needed for flat lying sediments.

An arithmetic average for 360 cross-bedding measurement ments show the mean current direction to be 186°. Averages computed from the strike of the ripple marks show an average current direction of 170°. Cross-bedding was measured at 15 foot intervals vertically where possible so that any variations in paleocurrent directions for one outcrop could be found. Maximum variation was found to be 127 degrees in one outcrop. However, the average variation per outcrop is on the order of 30 degrees. The maximum variation may be in two successive strata or in the two most widely separated strata in the outcrop. Dip of the foreset beds ranges from 11 to 36 degrees, with an overall average dip of 22 degrees. The variations in apparent paleocurrent directions found in most outcrops are indicative of rapidly changing current directions. Most outcrops show some degree of variation but some show as many as eight successive layers with exactly the same strike and dip of the foreset beds. Changing currents may have been in response to a braided type distributary system as found in a deltaic environment.

Poles normal to the foreset beds are plotted on an equal area stereonet (Fig. 9). Each point on the diagram represents the average direction of current of one outcrop. Because the same number of measurements was not made at every locality, each point does not represent the same number of measurements. There is a high degree of symmetry around the calculated arithmetic mean current direction, 186°.

The outcrop pattern of the Greenland and paleocurrent directions are shown on Plate 1. Each arrow plotted on the map represents the arithmetic average of the paleocurrent readings of the cross-beeding for a single locality. It was not always possible to obtain the maximum of six measurements

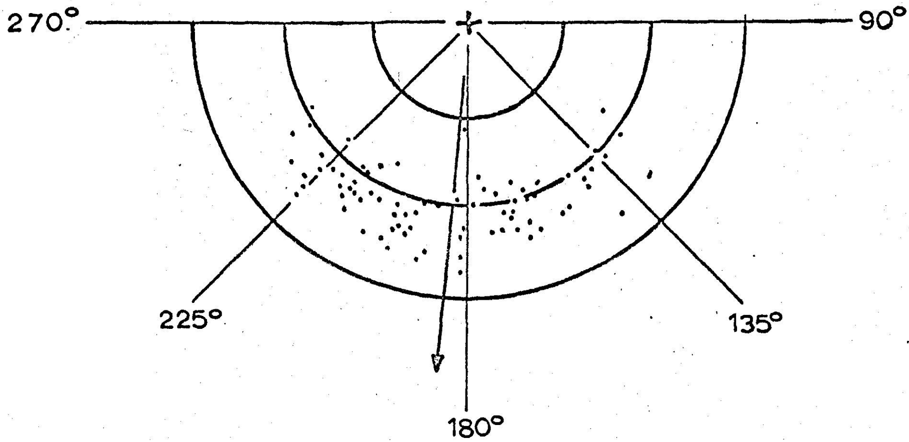

Fig. 9. Stereo-net plot of arithmetic average of cross-bedding measurements for each locality.

per outcrop. The direction of current flow is designated by the point of the arrow representing the locality.

Overturned Cross-Bedding

Overturned cross-bedding was observed in two localities, outcrops 68 and 138 (see Appendix Table 7 for location). Situated between normally cross-bedded strata are strata that exhibit overturned cross-bedding (Fig. 10). Graded bedding of each individual cross-stratum can be traced from normal dip through the vertical to overturned. The overturning appears to have occurred beggining approximately in the middle of the cross-bedded strata. No contortion of the beds occurred during overturning. The underlying stratum is undisturbed. Deposition of planar cross-bedding continued after overturning.

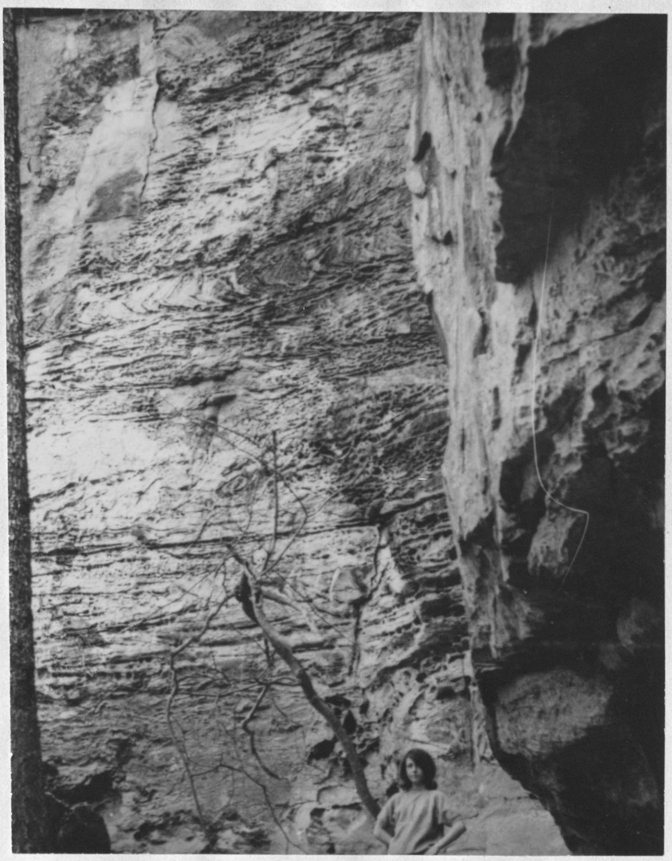

Fig. 10. Exposure of Greenland showing overturned cross-bedding. Overturned stratum is about 25 feet above girl's head. Outcrop 138.

The origin of the feature is thought to be some form of slump of the sand on the depositional slope. Possibly a process similar to soil creep may be responsible. Jones (1962) reported similar structures in the Bima Sandstone (Cretaceous age) in Nigeria. He concluded that they were caused by earthquakes, triggering off slumps of sand down the depositional slope, causing the overturning of the beds.

Other evidence for penecontemporaneous deformation of the Greenland is seen in Figure 11, a photograph of sample No. 282. This sample, not found in place, was once a part of a 1-inch layer of fine to medium sand. Asymmetrical ripple marks are developed on the upper surface. The sand was deposited on a ripple-marked surface as evidenced by the bottom casts of the sample. Then at some later time before lithification, the sand layer was deformed at an angle of 40 degrees from the strike of the ripple marks. The sample shows deformation without contorting the bedding. The sample may be a piece that was formed by the overturning of the cross-bedding.

In places one can observe worm borings in the Greenland. In some places the borings transect unstratified layers and in others the borings transect cross-bedding.

Fig. 11. Photograph of sample No. 282 showing deformation before lithification. Note that upper surface has ripple marks.

Giant Cross-Bedding

What appears to be giant cross-bedding can be seen while standing on top of the Greenland at the edge of the bluff in approximately the center of sec. 17, T. 15 N., R. 24 W., looking to the west across Kings River to the opposite bluff of the Greenland Sandstone (Fig. 12). The cross-strata appear to be about 15-20 feet thick and up to one hundred yards long. The apparent dip of the giant cross-bedding is south-southeast with the angle of dip about 20 degrees. Examination of the base of this outcrop of the Greenland reveals normal planar cross-bedding 18-24 inches thick and no indication of any other size of cross-bedding. A reason for not seeing larger scale cross-bedding at the base is that there is much overhang of the Greenland here, and the lower slope is so steep that one can observe only the basal part of the outcrop.

This giant cross-bedding may be some weathering feature such as weathering along joints or, in fact, may be due to large scale cross-bedding, such as might be expected in a deltaic environment. This feature has not been described in this area before, possibly because well exposed outcrops are rare. Perhaps a study of long, continous, vertical bluffs of the Greenland Sandstone may reveal more similar features when leaves are not in the way to obstruct the view.

Fig. 12. Telephoto view west of giant cross-bedding in well exposed bluff of Greenland Sandstone, NW$\frac{1}{4}$, sec. 17, T. 15 N. R. 24 W. The Greenland is approximately 50 feet thick.

Paleontology

The Greenland Sandstone is almost devoid of invertebrate fossils. Only in very few places can one find identifiable remains. Crinoid stem segments are the chief material identified in this area but bits and pieces of broken brachiopod shells are sometimes found. None of the original material of the fossils remain. As the Greenland is very porous, leaching by groundwater has removed all the original calcareous material and replaced it with limonite.

Fossil plant material is observed at almost every outcrop. For the most part, the plant fragments are unidentifiable. However, in several localities, good remains of Lepidodendron and Sigillaria trees are found (Fig. 13). The best preserved is a Lepidodendron trunk that was about $2\frac{1}{2}$ feet in diameter but due to compaction pressure, is now preserved as an oval 2 by $3\frac{1}{2}$ feet. All plant material have been filled by sand, replaced by limonite, or both, leaving only a limonite stained impression of the original material.

The abundance of plant fossils throughout the area, the presence of the fossils all through the Greenland vertically, and the fact that none are found in growth position, is a strong indication that they were floated into the area, became water-logged, and sank. The abundance of plant fossils indicates that the source area of the Greenland was prolific with vegetation and that the area of study of the Greenland was not far from the source where rivers were dumping sediments and plant remains into the shallow seas.

Fig. 13. Impressions of Lepidodendron and Sigillaria tree fossils in the Greenland Sandstone. Outcrop 137.

North-South Size Trend

Size analysis of twenty samples was made to determine if there is a north-south grain size trend that fits the paleocurrent pattern. Ten samples along a roughly east-west line in the northern end of the area and ten samples from the southern end, also in an east-west line, were sieved with the Ro-Tap shaker. This method of sampling was used because of the variations in character of the outcrops of the Greenland. In order to reduce the error from picking samples that may have been deposited by different velocities of currents, ten samples were taken at right angles to the general direction of flow.

Grain sizes were determined and plotted on cumulative curves. The median size at each locality was determined from these curves. An average of the median size of the ten samples from the north was found to be 0.39 mm and the average of median size from the ten samples from the south was 0.28 mm (Appendix Tables 3 and 4). This indicates that there is a definite north-south difference which suggest a north-south gradation of grain size of the Greenland Sandstone. This fits well with the idea that the strand line and source direction during the time of deposition was to the north (Quinn, personal communication).

Histograms of the size analyses were made to see any general trends in sorting. The largest percentage of grains were between 0.25 and 0.50 mm, making the Greenland basically a fine-grained sandstone. Cumulative curves were drawn and from these Q_1, Q_3, median grain size (Md), P_{10}, and P_{90} were determined. From these values the coefficient of sorting (So) for each of the twenty samples was computed. The coefficient of sorting ranged from 1.14 to 1.56 with an overall average of 1.33. Skewness and kurtosis were not computed. The figures for P_{10} and P_{90} are listed in Appendix Table 5.

Pettijohn (1957) gives figures for several degrees of sorting. A perfectly sorted sediment has a coefficient of sorting of 1.00 and a So value of less than 2.5 is indicative of a well-sorted sediment. It is pointed out that investigations have revealed that most nearshore marine sediments of sand-size material have a coefficient of sorting betwen 1.00 and 2.00 with 1.45 as the average. Even though sediments from other types of environments may have a similar coefficient of sorting, it is thought that the 1.33 average coefficient of sorting of the Greenland is more evidence that the Greenland Sandstone is of a shallow water marine origin.

Petrography

Binocular microscope examination of samples

120 samples of the Greenland were disaggregated into individual grains and observed through a binocular microscope. Particle size, shape, and degree of roundness were determined. Mineral compositions of the grains and of the cement were determined. Careful search was made for microfossils but none were observed. Feldspar and chert fragments are rare. A few small fragments (less than 1/16 mm) of what appeared to be weathered feldspars were observed. These fragments have been weathered to what appears to be a clay and are not clearly identifiable.

Chert particles are all larger than 4 mm, probably because chert weathers and is abraded faster than quartz after it becomes sand size and smaller. This is due to (1) the cherts being softer than quartz, and (2) the larger surface area exposed in proportion to the volume of the grain. The presence and relative abundance of heavy minerals were noted but no quantitative work was done with them. Grains of jasper, zircon, tourmaline, and dark unidentified minerals were observed. The vast majority of grains are quartz. Most of the quartz grains are colorless but a few are milky or pink. Several quartz grains contain dark inclusions but none were observed to contain bubble inclusions. Also observed were muscovite flakes, and one biotite flake. In general, the cleaner and finer the sand, the more abundant were the muscovite flakes. Samples with a high concentration of interstitial limonite revealed almost no muscovite flakes.

Sand grains and quartz overgrowths

Viewed through a binocular microscope, almost all quartz grains smaller than 0.50 mm were very angular, exhibiting many crystal faces, with only a few showing any degree of rounding. This is taken as evidence that the quartz grains have secondary crystalline overgrowths. Any quartz pebble in the purer sands with a high percentage of quartz cement shows faceting by quartz overgrowths. Two plagioclase grains identified in thin section are the only feldspars found.

In thin section, it was found that almost all the sand-size grains are angular to subangular with only those larger than 0.50 mm showing any degree of rounding. This angularity and the lack of voids between the grains leads the author to identify them as quartz grains with quartz overgrowths in optical continuity. Only very few grains were observed that definitely show the "dust ring" or "halos" of the old grain.

Several samples of a dark-gray, dense, fossiliferous limestone found 8 feet above the top of the Greenland in the upper Winslow in sec. 30, T. 16 N., R. 26 W. were dissolved in acid. Results show that the limestone is approximately 40 percent calcium carbonate, the remainder being almostall very fine to coarse quartz sand, with several quartz pebbles up to 8mm long. What was immediately noticeable in the insoluble residue was the small amount (about 8 percent) of clay-size material, and the fact that every quartz grain, regardless of size, is rounded to well rounded, with most of them showing polished surfaces. This is in distinct contrast to the angular to subangular shape that is very characteristic of the quartz grains of the Greenland.

As it is thought that the source direction and environment during deposition of the Greenland would not have changed much by the time the limestone 8 feet above the top of the Greenland was deposited, the author believes that the original Greenland sand was very clean, polished, rounded to well rounded, similar to the grains dissolved out of the limestone above it. In samples that contained a large amount of limonitic cement, the quartz grains are much less angular. This may be caused by a deficiency of quartz cement in this area, and the limonite filled in the interstitial voids.

Quartz pebbles

Quartz pebble conglomerates (Fig. 14) are scattered throughout the Greenland. These conglomerates are for the most part confined to the lower one-quarter of the unit, but in many locations, quartz pebble conglomerates are found throughout the Greenland. The oldest quartz pebble reported in this area is from the basal limestone conglomerate at the base of the Cane Hill Member of the Hale Formation. Saunders (1967) reported that one broken, rounded quartz pebble was recovered. The next major occurence of quartz pebbles is in the "caprock" of the Baldwin coal. The coal is absent in the

Fig. 14. Sample of Greenland Sandstone showing typical quartz pebble conglomerate.

area but quartz pebbles have been reported in the Bloyd Formation (Quinn, personal communication).

The major occurrence of quartz pebbles is in the basal conglomerate of the Greenland. The quartz pebbles are randomly scattered in the basal conglomerate, but higher in the Greenland, the quartz pebbles are found on bedding planes, both on the foreset beds and along bedding planes separating the cross-strata. Abundance of the quartz pebbles is variable. At some outcrops, there are many pebbles and at other outcrops, only a few are present. As the pebbles are found throughout the area, the abundance of pebbles may be useful in delineating areas of stronger currents during the time of deposition. This may help in identifying channels or areas where the local slope was greater than the regional slope.

An isopach map (Fig. 15) reveals three elongated areas of greater thickness that have a general north-south trend. Because these areas of greater thickness are parallel to areas of less thickness, it is thought that these thicker areas may represent channels due to erosion of the underlying units before the deposition of the Greenland. One deep "channel" in the extreme eastern part of the area supports the idea that this is a channel because in this area Gilley (1966) found the Greenland resting unconformably on the upper part of the Hale Formation. There is also a general thickening of the Greenland to the south and to the east. This thickening is in agreement with the idea that the

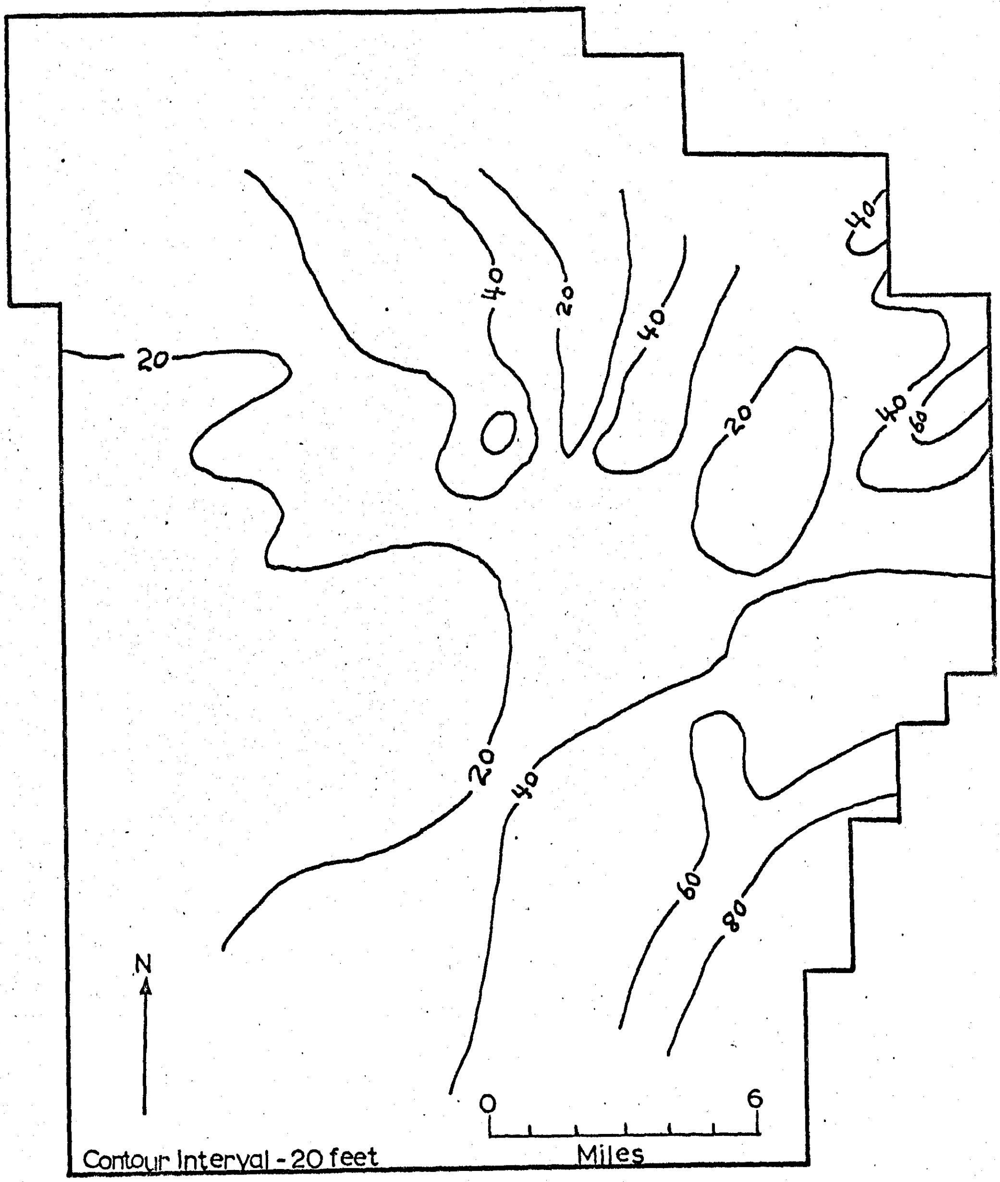

Fig. 15. Isopach of Greenland Sandstone in area of study, Madison County, Arkansas.

strand line during the time of deposition of the Greenland was somewhere to the west of Fayetteville, Washington County, Arkansas and to the north of the area of study (Quinn, personal comminication).

An overlay showing the location of outcrops containing quartz pebbles was placed on the isopach map and it revealed that the central thinnest area of the Greenland had very few or no quartz pebbles. It could be that there the currents were not strong enough to carry the quartz pebbles. However, other areas of thinness do not show any such relation. Overlays of transparencies showing the outcrops that contained plant fossils and clay pebbles do not reveal any noticeable trends when placed over the isopach map. Also any combination of overlays showing locations of quartz pebbles, clay pebbles, and plant fossils fail to show any trends.

Examination of the quartz pebble conglomerates shows them to be composed of quartz pebbles surrounded by a matrix of very fine to medium sand, cemented with quartz. The quartz pebbles are rounded to well rounded, but show a low sphericity. No broken pebbles were observed. Quartz pebbles from four samples, each containing 34 to 100 pebbles, were measured for maximum length, width and breadth of each pebble. The largest pebble is 36 mm long. Average for the three dimensions were determined and it was found that the maximum length is approximately double the breadth of the pebble (Appendix Table 1).

examining the quartz pebbles with a hend lens, pebbles that have a polycrystalline texture can be easily recognized. Pebbles showing this texture are thought to be metaquartzite. Other pebbles definitely have a single crystal metamorphic and vein quartz appearance. Fracturing and veining can be seen in many of the pebbles. Color ranges from milky white to light rose pink. Deposition of secondary quartz pacets some of the quartz pebble surfaces and gives many of the pebbles the appearance of possessing cleavage. If the pebbles are carefully rotated and the angle of "cleavage" noted, one finds that the angle is 60 degrees, the interfacial angle of crystal quartz. Thus the grains that earlier were thought to be feldspars because of the presence of "cleavage" proved to be quartz under close examination. An X-ray powder diffraction study confirmed the mineralogy of the pebbles.

Analysis of thin sections

A point count was made of nine thin sections using a Swift Point Counter coupled with a polarizing microscope. A total of 500 counts per thin section was made though 200 counts is usually considered enough when working with sediments. Because only a small number of minerals other than quartz are present, it was decided that the larger number of grain counts would give better results. The minerals in the thin sections are quartz (the most abundant), quartz cement, limonite, muscovite, orthoclase, plagioclase, and zircon. No other minerals were seen in thin section but the author believes after having observed samples of the Greenland through a binocular microscope, that a heavy mineral study of the Greenland would reveal a greater variety of minerals present.

Quartz grains were described according to even extinction, slightly undulatory extinction (having less than 10° difference in extinction angles per grain), strongly undulatory extinction (grains having greater than 10° extinction), or having polycrystalline texture, with sutured contacts between the grains. Quartz by volume ranges from 80.0 to 97.0 percent. Quartz by percent of minerals present ranges from ranges from 96.4 to 99.1 percent. The number of quartz grains showing some degree of undulatory extinction ranges from 24.8 to 75.2 with an average of about 50 percent. All quartz pebbles show strong undulose extinction or polycrystalline texture. Approximately 75 percent of the quartz pebbles ovserved in thin section have polycrystalline textures.

The author makes no assumption as to the origin of the quartz pebbles on the basis of extinction of the grains and pebbles. However, on the basis of the large size of the quartz pebbles (up to 36 mm long), the sutured contact between the quartz grains in many of the pebbles, and their large number, it is concluded the pebbles are probably of a metamorphic origin, either from a metaquartzite or a quartz vein. The volume of vein quartz is thought not to be sufficient to produce the large number of pebble which are found over the area and in the basal Pennsylvanian sediments of the Eastern Interior Basin to the northeast. Quartz from igneous rocks is not known to occur in the large pebble size in such quantities as found in the Greenland. Therefore, it is thought that the quartz pebbles were derived from a metamorphic terrain of from preexisting sediments to the north and northeast that contained metamorphic quartz pebbles.

The percentage of feldspars present is very low, ranging from zero to 1.2 percent. The majority of feldspar grains are of what appears to be orthoclase but are badly weathered and altered, making identification difficult, if not impossible. Two grains of plagiocalse were observed. Using the Michel Levy method, their compositions were determined. One grain shows a composition of An_{50}-Ab_{50} and the other has a composition of An_{53}-Ab_{47}. This marked similarity may indicate that such is near the true composition. Muscovite is present from 0.4 to 2.4 percent, and is more common in fine-grained clean samples. Only three grains of zircon were observed in the nine thin sections.

The almost total absence of feldspars and other less stable minerals may indicate that the quartz pebbles of the Greenland, and also the quartz grains that make up the Greenland, were derived from preexisting sediments. This would make the sediments of the Greenland second cycle or greater. Since quartz pebbles are resistant to abrasion, it is possible that the softer feldspar pebbles could have been present in the source area but had been eliminated by the time they reached the site of deposition. If this were the case, then one would suspect more feldspar grains of sand size and smaller in the detrital sediments of the Greenland. Accordingly, it is believed that the sediments of the Greenland represent multicycle transportation.

X-ray identification of cherts and limonite

While collecting field data and samples, particular attention was paid to the presence of chert pebbles and fragments. It was thought that if the chert pebbles could by some means be identified as Boone, Cotter, or any of the cherts that are well exposed around the Ozark Dome, a statement could be made concerning the Ozark Dome as a source area for part of the sediments of the Greenland Sandstone. Considerable search turned up only a few chert pebbles in the Greenland. A trip was made to the north to collect samples of Boone and Cotter cherts so that they could be matched with the samples from the Greenland. Samples were collected from the north of the area of study in the direction from which it was thought that the chert fragments in the Greenlnad might have come. An X-ray powder diffraction study revealed no characteristic minerals (only alpha quartz and calcite) in the cherts. See Appendix Table 8 for a description of the method used.

Two samples of Greenland that contained a high percent of limonite were X-rayed to determine their composition. Results show the limonite to be a mixture of hematite and goethite. A description of the method used is in Table 8.

THE WINSLOW ABOVE THE GREENLAND SANDSTONE

Deposition of the Greenland ended with the first influx of silt and clay into the area of deposition. There is no evidence of a break in deposition of the Winslow above the Greenland. The upper Winslow consists of alternating fine-grained sands and shales. For the most part the sands are very fine grain, thick to massive bedded, often with a large amount of quartz cement making the sands very resistant to erosion and forming discontinous small benches and ledges. These resistant layers cannot be traced horizontally for any great distance and it is thought that these sands tongue and wedge with the silts and shales. The shales and silty beds generally weather to a strong ocher color.

Gilley (1966) reported slump structures in the Winslow. The structures were formed penecontemporaneously with deposition of the sediments. Quinn (1959) has explained the origin of these structures as sliding after deposition of unconsolidated sediments on a foreslope with considerable initial dip. This fits well with the idea that the Green-land is of a shallow water near shore marine environment.

Accumulation of quartz pebbles did not end with the termination of the deposition of the Greenland. In many areas, quartz pebbles are found up in the upper Winslow. The general pebble size is around 4 mm and the abundance is much less than in the Greenland. Some of the upper layers of sandstone show good cross-bedding with a general south dip of the foreset beds. Also in several places where silty layers of the Winslow are exposed, layer on layer of asymmetrical ripple marks can be observed, all with the direction of current flow to the south. It is thought that a paleocurrent study made on the upper part of the Winslow will yield results similar to those shown by measurements in the lower member, the Greenland Sandstone.

A coal seam 12 to 18 inches thick was found in the upper Winslow approximatley 150 feet above the top of the Greenland in the SE$\frac{1}{4}$ of sec. 1, T. 14 N., R. 25 W. This location is directly west of the falls on Kings River where the river pours over the Greenland Sandstone. The coal is evidence that the upper part of the Winslow was emergent during part of the time of deposition. The coal is located between a series of alternating thick sands and thin shales and is directly overlain by a thick cross-bedded sandstone much like the Greenland. The coal is of no economic importance and probably cannot be traced laterally for any significant distance.

THE EASTERN INTERIOR BASIN AND ITS RELATION TO THE BOSTON MOUNTAINS

The Eastern Interior Basin, a broad intracratonic basin, is bordered on the southwest by the Ozark Uplift, and on the north and east by the Kankakee Arch, the Cincinatti Arch, and the Nashville Dome. The southern end of the basin was open to the sea during the deposition of the Chesteran (Mississippian) and lower Pennsylvanian sediments (Potter and Siever, 1956). Since 1953, much work had been done with the direction of sediment travel during the time of the deposition of the lower Pennsylvanian sediments. Most work has been done with the Caseyville and Mansfield Formations, both of Morrowan age. It has been stated by Potter and Siever (1956), Siever (1953), and Potter et al (1958), that the direction of paleocurrents during Morrowan time was to the southwest (Fig. 16). A minor source area was to the northwest. The sands of the Caseyville and Mansfield Formations range from fluvial channel to shallow water marine or deltaic type sedimentary bodies. The fact that the channel orientations and current directions are parallel in the Eastern Interior Basin indicates that the regional slope was to the south and southwest.

One of the characteristics of the sandstones of the Eastern Interior Basin is the presence of quartz pebble conglomerates. Quartz pebbles from the northwestern source are differentiated from those from the northeastern source by their more advance state of rounding and abrasion. The sediments derived from the northwestern source also contain a

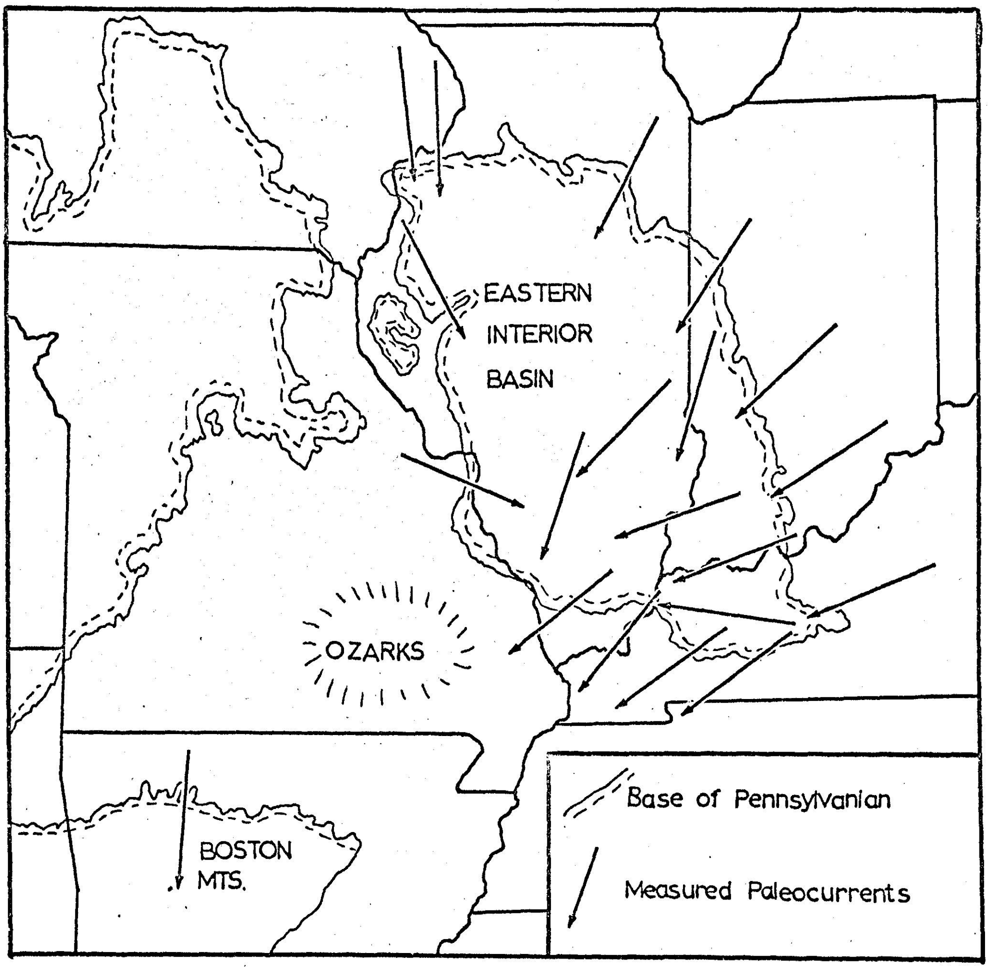

Fig. 16. Map showing relation of paleocurrents in Eastern Interior Basin and Boston Mountain region (modified from Potter and Siever, 1956).

lesser amount of feldspars (Siever and Potter, 1956). Most of the quartozse sandstones are interbedded with marine shales and limestones. These marine units indicate that the Eastern Interior Basin underwent many trangressions and regressions by the Pennsylvanian seas.

Thin section analyses by Siever and Potter (1956) have shown that the Pennsylvanian sands of the Eastern Interior Basin are predominantly quartzose sandstones. Observation of the extinction of the quartz grains under a polarizing microscope revealed the presence of metaquartzite grains, and quartz grains that show strong undulose extinction. These types of quartz grains are present in the Eastern Interior Basin in almost the same percentages as are found in the Greenland Sandstone. Non-undulatory quartz grains are dominant in the Eastern InteriorBasin just as they are in the Greenland. Potter and Siever (1956) said that the sediments from both sources, the northwest and the northeast, are several cycles removed from their igneous and metamorphic parent sources and clearly show that they were derived from preexisting sediments.

The striking similarities in lithology, mineralogy, age and paleocurrent directions of the Eastern Interior Basin and the Boston Mountain region are very good evidence that the two areas were continous during Morrowan time and were being subjected to the same environment. A strong link is shown by the presence of quartz pebbles in both the areas. No corresponding pebbles have ever been found in the Atokan sediments of the Ouachita Mountains and southeastern Oklahoma. This suggests that the Winslow Formation is a unique formation even though it has similarities with other units to the south.

If one looks at a geologic map of North America and observes the relative positions of the Eastern Interior Basin, the Ozark Dome, and the Boston Mountains, it would be observed that the Ozark Dome lies between the Eastern Interior Basin and the Boston Mountain region. Considering that the basic current direction in the Greenland is almost due south, but with a source direction from the northwest and northeast, it seems that the Ozark Dome area was not exposed during the time of the deposition of the Greenland. The Ozark Dome area was probably buried sometime during the deposition of the Hale or Bloyd Formations. Otherwise current direction patterns would show some diversion caused by such a positive area. Also, mineralogy of the Greenland failed to yield any direct evidence that the Ozark area was a positive feature and contributing sediments to the Greenland Sandstone at this time.

LATE MORROWAN GEOLOGIC HISTORY OF AREA

Deposition of the Bloyd Formation was terminated by the emergence of northwestern Arkansas. The area was tilted to the south and subjected to erosion (Quinn, 1959). Erosion continued in some areas to the extent that the sediments of the Hale Formation were exposed. This pre-Winslow erosion of the area is probably when the "channels" in the Grennland were developed. The channels probably represent the configuration of the drainage pattern prior to the re-advance of the late Morrowan sea. The start of the deposition of the Winslow Formation began with a large influx of clastic sediments into the area. The basal sheet sand comprises the Greenland Sandstone. All during the time of deposition of the Greenland only sand and quartz pebbles were being supplied to the area or the current competency was high enough to continue carrying the finer sediments to the south and out of the area. Sediments were being introduced from the north, from the general direction of the Eastern Interior Basin. The Greenland represents a shallow water near shore marine sand that was deposited by by rapidly changing currents. Deposition of the Greenland was probably during a very short period of time.

The event marking the end of the deposition of the Greenland was the first influx of shales and silts into the area. Alternating beds of silt, shale, and very fine-grained sandstones characterize the upper part of the Winslow Formation and may represent climatic conditions of alternating wet and dry periods.

The coarse conglomeratic sands and pebbles of the Greenland Sandstone are thought to be a result of removal of large volumes of material from lands to the north and northeast during a period of a humid climate. Any evidence of post-Winslow units being deposited in the area of study has since been removed by erosion.

SUMMARY

1. The Greenland Sandstone is a very fine- to medium-grained, light yellow-tan, cross-bedded, ripple-marked, quartzose sandstone with quartz cement and some interstitial limonite.
2. The Greenland rests with unconformaty on lower Morrowan sediments.
3. The basal contact of the Greenland is very sharp and regular with little evidence of channeling.
4. The basal conglomerate clay pebbles may be derived from the underlying units.
5. Cross-bedding measurements show a paleocurrent direction of 186°.
6. Ripple mark measurements show a paleocurrent direction of 170°.
7. Overturned corss-bedding is present in the Greenland.
8. Giant cross-bedding may be present in the Greenland.
9. There is a north-south grain size trend with the northern sediments being coarser.
10. Invertebrate fossils are rare but plant fossils are common in the Greenland.
11. The majority of quartz grains have quartz overgrowths.
12. Quartz pebbles are common, may be up to 36 mm long, and are probably of a metamorphic origin.
13. Size analysis shows that the Greenland has a coeffieient of sorting close to the average determined for shallow water marine sands.

14. Thin section analysis shows the Greenland to be almost 100 percent quartz.
15. X-ray identification of cherts failed to reveal any minerals characteristic of specific formations.
16. X-ray identification of limonite revealed it to be composed of hematite and geothite.
17. Differential weathering of underlying units below the Greenland, by action of groundwater and mechanical weathering by freezing, causes overhangs of the Greenland.
18. The overlying upper Winslow Formation consists of alternating sands and shales with one coal seam.
19. The sediments of the Greenland Sandstone and the lower Pennsylvanian sediments of the Eastern Interior Basin, on the basis of paleocurrents, lithology, mineralogy, and age similarities indicate that the two areas were connected during Morrowan tmme.
20. The area was subjected to erosion and tilting to the south before the deposition of the Greenland. Erosion may have formed channels in the base of the Greenland.

Future work that might be done includes a continued study of the paleocurrent directions of the Greenland Sandstone for all of northwestern Arkansas; a paleocurrent study of the upper Winslow Formation to determine if conditions during the time of deposition of the Greenland prevailed during the time of deposition of the upper Winslow Formation; more work with cherts to try to determine what units were exposed to the north during the time of the deposition of

Greenland; and a more closely measured isopach of the Greenland to try to determine the actual localities of pre-Greenland erosional channels.

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A P P E N D I X

Table 1- Averages of the three dimensions measured on the quartz pebbles. Measurements are in millimeters.

Sample No.	Length (mm)	Width (mm)	Breadth (mm)	No. of Pebbles
138	17.0	11.5	7.4	35
199	16.8	11.7	9.3	39
167	17.9	11.6	8.3	100
202	14.8	10.0	7.4	34

Table 2. Tabulation of size analyses of the ten samples from from the northern half of the area of study. Upper figures are in weight percent and lower figures are cumulative percent.

SAMPLE NO.	SIEVE SIZE					
	2.0 (mm)	1.0 (mm)	0.50 (mm)	0.250 (mm)	0.125 (mm)	PAN
112	0.0 0.0	1.4 1.4	28.2 29.6	63.2 92.8	4.1 96.9	3.1 100.0
128	0.0 0.0	2.4 2.4	24.5 26.9	62.4 89.3	6.3 95.6	4.4 100.0
134	5.4 5.4	9.5 14.9	31.5 46.4	43.7 90.1	6.2 96.3	3.7 100.0
146	0.1 0.1	2.1 2.2	21.5 23.7	57.6 81.3	11.8 93.1	6.9 100.0
153	0.0 0.0	1.4 1.4	21.5 22.9	64.8 87.7	8.1 95.8	4.1 99.9
156	0.0 0.0	0.6 0.6	6.4 7.0	41.9 48.9	44.1 93.0	6.9 99.9
159	0.0 0.0	0.5 0.5	5.3 5.8	76.1 81.9	16.0 97.9	2.1 100.0
165	0.0 0.0	0.3 0.3	5.9 6.2	80.0 86.2	11.3 97.5	2.5 100.0
171	0.0 0.0	0.8 0.8	12.0 12.8	65.3 78.1	16.1 94.2	5.8 100.0
207	1.7 1.7	3.7 5.4	27.0 32.4	52.3 84.7	11.5 96.2	3.7 99.9

Table 3. Tabulation of size analyses of the ten samples from the southern half of the area of study. Upper figures are weight percent and lower figures are cumulative percent.

SAMPLE NO.	SIEVE SIZE 2.0 (mm)	1.0 (mm)	0.50 (mm)	0.250 (mm)	0.125 (mm)	PAN
213	0.2 0.2	0.9 1.1	4.5 5.6	48.7 54.3	31.5 85.8	14.1 99.9
226	0.0 0.0	0.0 0.0	0.0 0.0	13.9 13.9	55.0 68.9	31.0 99.9
227	0.3 0.3	1.3 1.6	12.5 14.1	61.4 75.5	16.5 92.0	8.0 100.0
231	0.0 0.0	1.6 1.6	6.8 8.4	51.7 60.1	32.9 93.0	7.0 100.0
233	0.1 0.1	0.4 0.5	7.4 7.9	70.7 78.6	13.0 91.6	8.4 100.0
269	0.1 0.1	0.8 0.9	5.2 6.1	61.0 67.1	21.7 88.8	11.1 99.9
270	0.1 0.1	1.1 1.2	5.5 6.7	48.2 54.9	34.0 88.9	11.0 99.9
274	0.0 0.0	0.5 0.5	5.1 5.6	62.2 67.8	23.0 90.8	9.1 99.9
279	0.0 0.0	0.0 0.0	5.5 5.5	12.0 17.5	56.2 73.7	26.3 100.0
284	0.0 0.0	0.0 0.0	15.5 15.5	50.2 65.7	15.0 80.7	19.3 100.0

Table 4. Tabulation from cumulative curves of the ten samples from the northern half of the area of study.*

SAMPLE No.	Q_1 (mm)	Q_3 (mm)	Md (mm)	P_{90} (mm)	P_{10} (mm)	So
112	0.35	0.59	0.43	0.77	0.26	1.30
128	0.34	0.53	0.43	0.79	0.24	1.25
134	0.40	0.75	0.47	1.48	0.24	1.37
146	0.30	0.47	0.40	0.73	0.17	1.25
153	0.33	0.48	0.38	0.75	0.21	1.20
156	0.18	0.38	0.24	0.47	0.13	1.45
159	0.33	0.43	0.37	0.40	0.20	1.14
165	0.33	0.43	0.40	0.46	0.21	1.14
171	0.29	0.43	0.38	0.58	0.18	1.22
207	0.37	0.59	0.47	0.85	0.21	1.26

* In order to conform with standard statistical usage, Q_1 is the 25 percentile with 25 percent smaller and 75 percent larger, Q_3 is the 75 percentile with 75 percent smaller and 25 percent larger. Median or the "average" size is the grain size that 50 percent of the grains are larger and 50 percent are smaller. P_{10} is the grain size that 10 percent are larger and 90 percent are smaller. The coefficient of sorting (So) was computed so that So is the square root of the ratio of the quartiles, Q_3/Q_1, where Q_3 is a larger number than Q_1 (Pettijohn, 1957).

Table 5. Tabulation from cumulative curves of the ten samples from the southern half of the area of study.

SAMPLE NO.	Q_1 (mm)	Q_3 (mm)	Md (mm)	P_{90} (mm)	P_{10} (mm)	So
213	0.18	0.40	0.27	0.44	0.09	1.49
226	0.11	0.21	0.17	0.26	0.07	1.38
227	0.25	0.44	0.37	0.61	0.15	1.32
231	0.20	0.38	0.33	0.48	0.14	1.37
233	0.27	0.43	0.37	0.49	0.16	1.26
269	0.21	0.38	0.33	0.45	0.11	1.38
270	0.18	0.37	0.28	0.45	0.10	1.43
274	0.21	0.39	0.33	0.46	0.13	1.36
279	0.11	0.25	0.17	0.40	0.07	1.51
284	0.18	0.44	0.35	0.60	0.08	1.56

Table 6. Tabulations from thin section point counts. Figures are in percent.

QTZ.- Unstrained quartz
MET.- Metaquartzite
S.U.- Strongly undulatory quartz
SL.U.- Slightly undulatory quartz
QTZ.C.- Quartz cement
LIM.- Limonite cement
MUS.- Muscovite
ORT.- Orthoclase
PL.- Plagioclase
Z.- Zircon.

SAMPLE NO.	QTZ.	MET.	S.U.	SL.U.	QTZ.C.	LIM.	MUS.	ORT.	PL.	Z.
124	50.2	1.2	9.2	14.4	5.0	19.0	1.0	0.0	0.0	0.0
197	52.0	2.0	3.0	29.2	8.2	2.8	2.8	0.0	0.0	0.0
198	32.0	11.4	20.8	23.0	9.8	0.8	1.0	0.2	0.0	0.0
206A	42.8	13.6	17.2	21.2	1.8	1.8	1.0	0.2	0.0	0.0
226	49.9	14.4	12.6	13.4	5.4	2.2	2.4	0.4	0.2	0.4
228	27.0	21.8	20.8	15.8	7.0	6.4	0.4	0.2	0.0	0.2
251	49.2	10.8	16.2	11.8	3.4	4.6	1.2	0.8	0.4	0.0
252A	14.0	23.4	44.2	7.6	3.8	5.8	2.0	0.2	0.0	0.0
252B	29.6	13.6	24.8	25.0	0.4	6.8	2.4	0.0	0.0	0.0

Table 7. Paleocurrent indicator measurements by outcrop number. Also included are outcrop locations and outcrop numbers of samples used in size analyses, thin sections, or photographs. Cross-bedding measurements are given by azimuth of foreset bed, dip of foreset bed, and direction. For example, in Outcrop 5 the foreset bed strikes 260 degrees, with a dip of 23 degrees to the south. Ripple mark measurements are given by strike of the ripple marks and then direction of current flow. For example, in Outcrop 1 the strike of the ripple mark is 272 degrees with a southerly direction of current flow. Special abbreviations for location of outcrops are: NC-north center, SC-south center, WC-west center, and EC-east center.

OUTCROP NO.	LOCATION SEC.	TWP. N.	RNG. W.	CROSS-BEDDING	RIPPLE MARKS	SAMPLE NO.
1	SC 25	17	24		272-S 269-S	
2	NW 36	17	24		295-W	
3	SE 3	16	24		260-S 247-S	
5	NC 7	16	23	260-23S 260-23S 260-23S 260-23S 260-23S 260-23S		
6	SC 7	16	23	270-11S 270-11S 270-11S 270-11S 270-11S		112
7	c 24	16	24	305-16W 322-26W 231-17S 310-23W 210-21W 220-18S		
9	c 30	16	23	220-22S 310-25W 310-18W 320-18W 220-18W 320-23W 325-21W	360-W	

Table 7 (Continued)

14	NW 13	16	25		290-S 355-W 360-W	
15	NE 14	16	25		290-S 290-S	
19	NE 29	16	24	239-21S 240-20S 236-17S 230-18S 235-19S 237-23S		134
21	SW 29	16	25		282-S 291-S	
24	NE 9	16	25	276-21W 316-18W 310-16W		
25	NC 17	16	25	252-16S 306-19W 277-22S		159
27	c 7	16	25	220-26S		
29	WC 33	17	25	331-22W 294-26W 312-19W 297-18S 322-19W 316-23W		
30	W 26	17	25	291-18S 311-31W 341-27W		165
31	NW 36	17	25		340-W	
32	NE 36	17	25		75-S 82-S 77-S	
33	c 16	17	25	347-27W 307-23W 321-22W 296-21S 319-27W 220-23S		

Table 7 (Continued)

34	NE 31	17	25	285-19S 281-27S 288-24S		171
35	SE 36	17	26	291-23S 289-24S 287-18S 285-27S		
36	W 26	17	26	321-22W 331-27W 307-23W 316-18W 318-26W 301-26W		
37	NE 35	17	26	317-20W 301-19W 227-26S 322-27W 311-22W 236-27S		
38	SW 11	16	26	311-19W 309-22W 326-13W		
40	NE 4	16	26			206
42	SC 6	16	26	191-21S 319-22W 199-30S 186-33S 207-27S 276-31S		207
45	W 22	16	26	217-19S		
47	SW 27	16	26	297-19S 289-23S 301-21W		
50	SW 24	16	26		196-S 207-S 225-S	
51	NW 19	16	25	296-23S 310-21W 299-26S 294-19S		

Table 7 (Continued)

52	SW 19	16	25	316-26W 291-22S 307-26W 310-21W 307-18W 298-23S	283-S 287-S 276-S	
53	SE 30	16	25	320-19W 314-21W 317-22W		
54	SE 36	17	24		220-S 235-S	
56	WC 15	16	25		260-S 260-S 270-S	124
57	SC 18	16	24			128
60	NC 20	16	24	310-28W 300-16W 305-10W 300-32W		
61	SE 20	16	24	280-20S 300-22W		
62	SE 24	15	25	320-15W 285-25S 285-21S 305-22W 280-25S 310-16W		
63	EC 19	16	23	310-21W 300-23W		
64	NC 25	16	24	347-21W 330-20W 335-21W 275-18S 345-19W 352-17W	360-W 342-W 5-W	146
65	SC 22	16	25	227-22S 218-23S 321-21W 220-28S 231-17S 317-19W		

Table 7 (Continued)

66	EC 21	16	25	227-16S 221-21S 285-20S 231-19S 280-23S 282-23S		
67	WC 21	16	25	290-21S 275-21S 293-20S 287-36S 280-23S 288-24S		153
68	SC 15	16	25	310-25W 276-22S 287-21S 290-18S 280-23S 297-24S	80-S 97-S	
69	WC 16	16	25	222-18S 317-27W 225-19S 321-22W	45-S 75-S	156
70	NC 35	17	25	317-18W 304-17W 317-23W 298-21S 310-19W 302-27W	285-S	
73	NW 10	16	24		272-S 57-S 69-S	
74	NW 9	16	24	220-17S 221-23S 231-19S	227-S 242-S 219-S	
75	SC 23	16	24	227-19S 232-24S 340-31W 221-24S 334-27W 329-30W	219-S 240-S 267-S	

Table 7 (Continued)

76	c	26	16	24	227-27S 319-31W 222-22S 314-26W		
77	NE	36	16	24	227-18S 216-31S 337-27W 231-22S 329-27W 342-24W		
80	WC	25	16	25	321-18W 327-27W 331-16W	271-S 282-S 274-S	
81	c	27	16	25		281-S 292-S 287-S	
82	SE	34	16	25	307-19W	340-W	
83	EC	4	15	25		281-S 283-S 242-S	
84	c	32	16	25	319-18W 220-19S 327-31W		
85	SC	31	16	24	295-27S	196-S	
86	NW	5	15	24	227-18S 219-27S 319-19W 231-26S 206-21S 302-11W	271-S 287-S	197
87	SC	5	15	24	207-16S 219-19S	262-S	198
88	SE	3	16	26	347-31W 326-19W 309-16W		
89	SW	35	17	26	316-19W 310-31W 310-27W 327-27W 322-27W 301-23W		

Table 7 (Continued)

90	NW	6	14	24	247-18S 239-19S 271-20S 241-18S 242-24S 256-19S	241-S 256-S	213
92	NE	22	16	26	291-18S 237-27S 247-30S 246-17S 255-26S 262-19S	217-S 222-S 247-S	
93	WC	11	14	26	311-16W 291-22S 308-18W		
94	c	2	14	26	351-24W 276-19S 291-21S 358-19W 272-26S 262-22S		231
95	NW	31	15	25	272-19S 254-22S 261-27S 259-22S		233
96	NW	30	15	25	297-19S 256-17S 231-22S		
98	SW	1	14	26	249-18S 237-22S 256-17S 242-21S		
99	WC	17	14	25	241-22S 249-21S 237-27S		
100	SC	8	14	25	242-19S 239-27S		226
101	SW	18	14	25	247-18S 267-22S 252-14S		227

Table 7 (Continued)

102	WC	7	14	25		242-S 249-S 262-S	228
103	WC	36	15	26	277-19S 282-30S 252-21S 291-27S 267-26S 262-23S	205-S 219-S 252-S	
104	c	29	15	25	291-30S 299-22S 277-27S		
105	EC	20	15	25	217-19S 202-21S 229-22S		
107	NE	23	15	26	297-23S 276-21S 301-27W 269-22S		
108	NC	13	15	26	316-19W 337-26W 307-23W 342-22W 296-24S 325-27W		
110	SW	6	15	25	312-21W 312-19W 286-22S 297-19S 314-23W 307-23W		
115	c	16	15	26			251
116	NW	10	15	26			252
118	SE	27	16	26	271-19S 321-17W 297-16S		
119	SC	21	16	24	249-19S 248-20S 267-16S 256-20S 271-27S 265-23S		

Table 7 (Continued)

120	EC 32	16	24	259-18S		
				271-19S		
				277-26S		
				267-21S		
				262-18S		
				257-19S		
121	NC 31	16	24	261-19S		
				260-19S		
				272-13S		
123	SW 4	15	24	260-19S	246-S	
				291-18S	249-S	
				256-26S		
				271-22S		
				249-17S		
				221-25S		
124	c 2	15	24	321-19W	276-S	
				341-19W	279-S	
				299-27S	276-S	
				327-19W		
				297-26S		
				307-21W		
125	SE 2	15	24	309-27W	270-S	
				297-25S	289-S	
				267-21S	286-S	
				301-26W		
				311-26W		
				269-23S		
128	SW 15	15	24			269
129	SC 30	15	25	240-26S		270
				271-18S		
				276-28S		
				252-17S		
				296-24S		
				299-23S		
130	c 31	15	24	247-27S	267-S	
				256-24S	271-S	
				231-23S	266-S	
				249-24S		
				244-27S		
				271-19S		
131	NE 30	15	24			274

Table 7 (Continued)

132	NE 29	15	24	247-21S 246-26S 248-20S 249-27S 257-26S 262-21S	271-S 292-S 256-S	
133	SW 16	15	24	256-13S 273-20S 272-19S 272-19S 261-19S 247-21S	281-S 297-S 286-S	
134	SE 33	15	24	227-27S 236-20S 231-21S 225-26S 247-18S 229-19S	279-S 262-S 263-S	279
135	c 17	15	24	219-18S 231-23S 226-22S 217-22S 219-22S 227-21S	240-S 247-S 242-S	
136	c 9	15	24	227-23S 246-23S 245-20S 221-21S 223-24S 237-23S		282
137	SE 18	15	24	237-20S 262-18S 249-21S 246-21S 251-16S 256-22S	240-S 262-S 231-S	284
138	NW 20	15	24	221-18S 227-21S 234-22S 219-15S 236-23S 236-24S		
139	SW 8	15	24	261-23S 253-24S 240-26S 256-21S 249-23S 257-22S	220-S 219-S 228-S	

Table 8- Method of mineral identification for the cherts and limonite.

Machine- General Electric XRD-5 X-ray powder diffraction machine

Kilovolts- 40

Millamps- 15

Time constant- 2.0

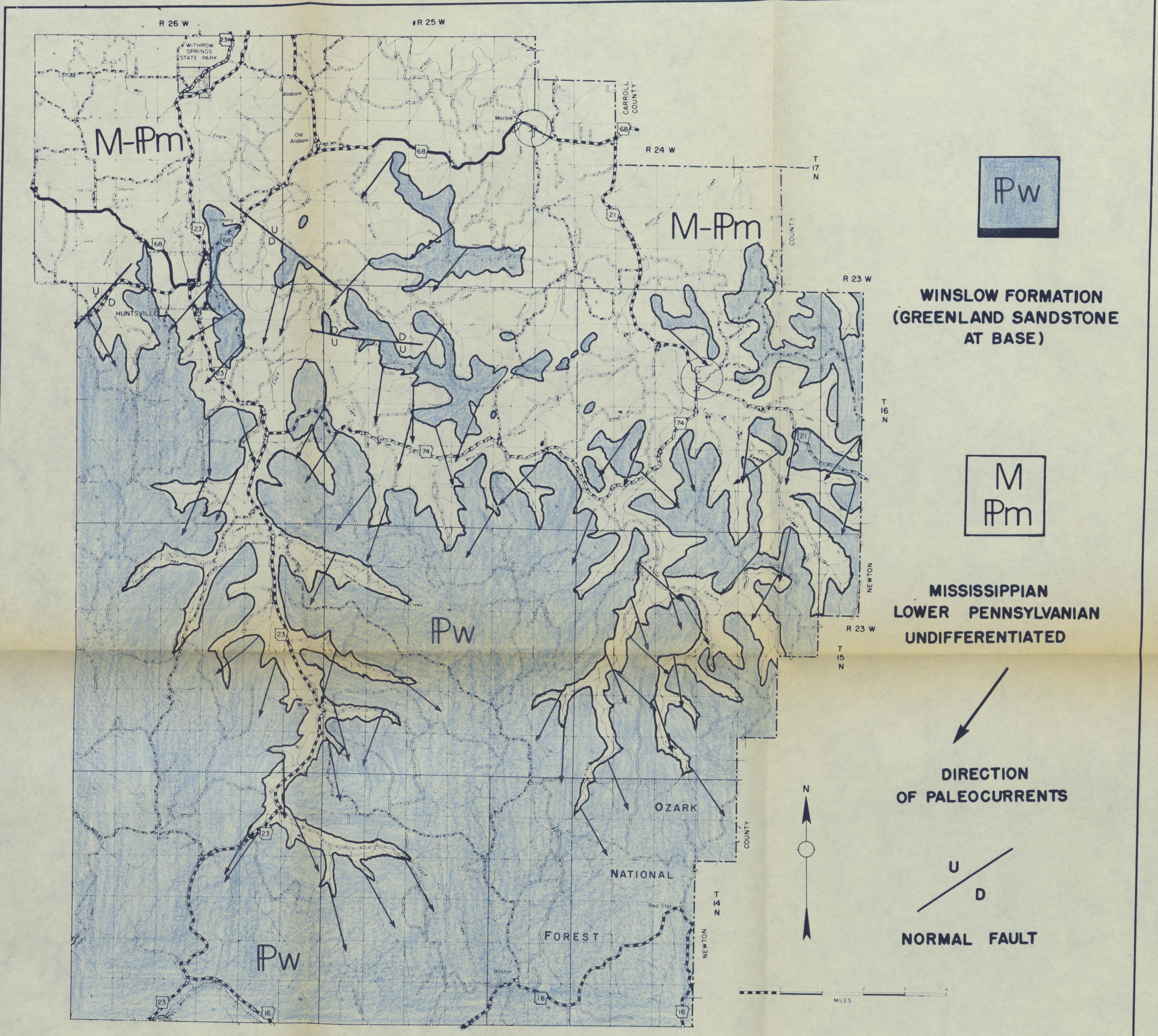
Rate- 500 cps

Scan speed- 2° 2θ/ minute

Angles- 20° 2θ to 75° 2θ

Grinding- seven minutes in ball mill

Settings for the chert and limonite samples were the same except the limonite samples were started at 10° 2θ to observe any clay peaks that might be present.



MAP OF WINSLOW FORMATION WITH GREENLAND SANDSTONE MEMBER AT BASE, EASTERN MADISON COUNTY, ARKANSAS

BASE MAP FROM MADISON COUNTY HIGHWAY MAP, 1963

LARRY F. SANDLIN 1967